UNITED STATES PATENT APPLICATION FOR

AUTOMATIC DIGITAL IMAGE ENHANCEMENT

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AUTOMATIC DIGITAL IMAGE ENHANCEMENT

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

5   The present invention relates to the field of digital image processing. More specifically, the present invention relates to a method and apparatus for enhancement of digital images.

RELATED ART

10   Digital cameras and scanners have become increasingly popular in recent years for generating digital images. Because of the recent decreases in cost for digital cameras and scanners, more and more photo pictures are generated, transmitted and saved in digital forms by amateur users instead of professionals. Unlike professional photos, photos produced by amateur users

15   tend to suffer from poor image quality. These image quality problems result from under exposure, over exposure, poor lighting conditions, bad focus, inappropriate scanning processes, etc.

For the above reasons, it is important to design ways to guarantee picture

20   quality in a way that requires the least user input and that works mainly on itself, so that even amateurs can use it. The point-and-shoot camera is a good example of a product that is designed to meet this requirement.

Digital processing methods typically focus on the picture capture stage,

25   i.e., exposure setting, focus control, etc. The state of the art in digital camera

HP-10011098

design has been quite successful by emulating traditional analog film cameras. However, camera design can not solve all of the quality problems because picture quality is partially a psychological problem.

5   Digital post-processing methods have been designed that include image enhancement algorithms that improve image quality. Among recent image enhancement algorithms, a tone mapping algorithm is generally employed for adjusting the distribution of pixel values to produce better quality. The use of a tone mapping algorithm has been quite successful for satellite photos, airborne

10   photos and medical images. For these applications, a major quality enhancement purpose is to illustrate the details of the images. However, these algorithms do not work well on consumer photos, because for consumer photos, the quality enhancement is more of a psychological problem than a mathematical problem, and detail illustration is not necessarily an important

15   factor for quality evaluation.

Recently, some computer programs have been developed for digital image enhancement for consumer pictures. An example of a successful program that provides digital image enhancement is Photoshop, a software

20   product manufactured by Adobe. Though Photoshop includes a large repository of processing tools, it does not offer automatic processing. Users have to choose appropriate tools and parameters for their pictures based on their own judgment. Therefore, this is not a good tool for amateur users as they cannot easily determine the proper tools to use or the proper parameters to

25   specify.

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What is needed is a method and apparatus for enhancing a digital image that produces images that are perceived to be of good image quality. In particular, a method and apparatus for enhancing a digital image is needed that

5   produces an enhanced digital image that is perceived to be of good image quality to amateur users. Also, what is needed is a method and apparatus that meets the above needs and that is automatic. Moreover, a method and apparatus is needed for enhancing a digital image that meets the above needs and that does not require user input.

SUMMARY OF THE INVENTION

The present invention provides a method and apparatus for enhancing a digital image that is automatic and that does not require user input. In addition, the method and apparatus of the present invention produces an enhanced

5   image that is perceived to be of good image quality.

The majority of consumer photos include human faces. According to recent psychological studies, face region lightness plays an important role in picture quality evaluation. The method for enhancing a digital image of the

10   present invention incorporates this psychological factor to produce an enhanced image that is perceived to be of good image quality.

In one embodiment of the present invention, each digital image is converted from its original format into a format suitable for easy manipulation.

15   In the present embodiment, the digital image is converted from its original format into CIE L *a*b* color space. Conversion of a digital image from its original format into L *a*b* color space as is more fully described in "Color Space Conversions," by Adrian Ford and Alan Roberts, September 1996, which is available at www.inforamp.net/~poynton/PDFs/coloureq.pdf, which is

20   incorporated herein, by reference, in its entirety. The resulting format includes a L* component that represents the lightness of each pixel of the image. The format also includes a* and b* components that represent the chromatic features of each pixel of the image.

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The method for enhancing a digital image of the present invention locates human faces within a digital image. In the present embodiment, a face detection algorithm is used to detect human faces. The digital image is then analyzed, including analysis of the regions determined to be human faces and

5   the analysis of the digital image as a whole. A tone mapping function is then determined for enhancing the image quality of the digital image. The tone mapping function is determined using both the analysis of detected faces and the analysis of the image as a whole to obtain a tone mapping function that incorporates both psychological factors (e.g., average face region lightness

10   and average picture lightness) and signal factors (e.g., digital resolution, face region contrast, histogram uniformity, and noise issue).

The tone mapping function is then applied to the digital image so as to produce an enhanced digital image. In one embodiment the tone mapping

15   function is directly applied to each pixel element to obtain an enhanced digital image. In another embodiment of the present invention a lookup table is generated that represents the tone mapping function. The look up table is applied to the entire digital image to map an enhanced digital image. More particularly, in the present embodiment, each lightness (L*) component is

20   altered according to the values stored in the lookup table to generate an enhanced digital image having altered tone values. The components that represent the chromatic features are not altered (i.e., a* and b* components are not changed).

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The present invention is automatic. That is, the user needs only initiate operation of a program that performs the method of the present invention. All of the steps of the present invention are then performed automatically. Therefore, there is no need for a user to choose between a variety of tools to determine the

5   appropriate tools to use as is required in prior art methods.

The method and apparatus of the present invention does not require that the user provide any input. Therefore, there is no need for a user to determine various parameters that must be specified as is required by prior art methods.

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Accordingly, the method and apparatus of the present invention is a good tool for amateurs to use as they will not be required to determine the proper tools to use or determine the proper parameters to specify as is required by prior art processes. In addition, the method and apparatus of the present

15   invention is easy to use since the user needs take no action other than initiation of the program that is operable to perform the method of the present invention. Also, the method and apparatus of the present invention produces enhanced images that are perceived to be of good image quality.

20   The present invention provides these advantages and others which will no doubt become obvious to those of ordinary skill in the art after having read the following detailed description of embodiments in accordance with the present invention.

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BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a logical block diagram of an exemplary computer system in accordance with an embodiment of the present invention.

5   Figure 2 is a diagram that illustrates a method for enhancing a digital image in accordance with one embodiment of the present invention.

Figure 3 is a diagram that illustrates a method for enhancing a digital image that uses a look-up table and in which the original image is converted

10   into L*a*b* space in accordance with one embodiment of the present invention.

Figure 4 is a diagram that shows an exemplary two dimensional feature space in which the energy function for psychological evaluation is performed in accordance with an embodiment of the present invention.

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Figure 5 is a diagram of a state machine depiction of the tone mapping function of the present invention based on nine-category classification of input images in accordance with an embodiment of the present invention.

20   Figure 6 is a graph of an exemplary tone mapping curve in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Reference will now be made in detail to the preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings. While the invention will be described in conjunction with the preferred

5   embodiments, it will be understood that they are not intended to limit the invention to these embodiments. On the contrary, the invention is intended to cover alternatives, modifications and equivalents, which may be included within the spirit and scope of the invention as defined by the appended claims. Furthermore, in the following detailed description of the present invention,

10   numerous specific details are set forth in order to provide a thorough understanding of the present invention. However, it will be obvious to one of ordinary skill in the art that the present invention may be practiced without these specific details. In other instances, well known methods, procedures, components, and circuits have not been described in detail as not to

15   unnecessarily obscure aspects of the present invention.

Some portions of the detailed descriptions which follow are presented in terms of procedures, logic blocks, processing, and other symbolic representations of operations on data bits within a computer or digital system

20   memory. These descriptions and representations are the means used by those skilled in the data processing arts to most effectively convey the substance of their work to others skilled in the art. A procedure, logic block, process, etc., is herein, and generally, conceived to be a self-consistent sequence of steps or instructions leading to a desired result. The steps are those requiring physical

25   manipulations of physical quantities. Usually, though not necessarily, these

physical manipulations take the form of electrical or magnetic signals capable of being stored, transferred, combined, compared, and otherwise manipulated in a computer system or similar electronic computing device. For reasons of convenience, and with reference to common usage, these signals are referred

5   to as bits, values, elements, symbols, characters, terms, numbers, or the like.

It should be borne in mind, however, that all of these terms are to be interpreted as referencing physical manipulations and quantities and are merely convenient labels and are to be interpreted further in view of terms

10   commonly used in the art. Unless specifically stated otherwise as apparent from the following discussions, it is understood that throughout discussions of the present invention, discussions utilizing terms such as "determining," "locating," "analyzing," "applying," "calculating," or the like, refer to the action and processes of a computer system, or similar electronic computing device,

15   that manipulates and transforms data. The data is represented as physical (electronic) quantities within the computer system's registers and memories and is transformed into other data similarly represented as physical quantities within the computer system memories or registers or other such information storage, transmission, or display devices.

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EXEMPLARY COMPUTER SYSTEM IN
ACCORDANCE WITH THE PRESENT INVENTION

Figure 1 is a block diagram of one embodiment of an exemplary

25   computer system 100 used in accordance with the present invention. It should be appreciated that system 100 of the present embodiment is well suited to be

implemented as any of a number of different types of computer (e.g., portable

laptop computer, desktop computer, server computer, personal digital assistant,

palmtop computer and the like). Within the following discussions of the present

invention, certain processes and steps are discussed that are realized, in one

5   embodiment, as a series of instructions (e.g., software program) that reside

within computer readable memory units of computer system 100 and executed

by processor(s) of system 100. When executed, the instructions cause system

100 to perform specific actions and exhibit specific behavior which is described

in detail below.

10

In general, computer system 100 of Figure 1, used by an embodiment of

the present invention, comprises an address/data bus 110 for communicating

information, one or more central processors 102 coupled with bus 110 for

processing information and instructions. Central processor unit 102 may be a

15   microprocessor or any other type of processor. The computer system 100 also

includes data storage features such as a computer usable volatile memory unit

104 (e.g., random access memory, static RAM, dynamic RAM, etc.) coupled with

bus 110 for storing information and instructions for central processor(s) 102, a

computer usable non-volatile memory unit 106 (e.g., read only memory,

20   programmable ROM, flash memory, EPROM, EEPROM, etc.) coupled with bus

110 for storing static information and instructions for processor(s) 102. System

100 also includes an optional signal input and output device 108 coupled with

bus 110 for enabling system 100 to interface with other electronic devices. In

one embodiment of the present invention, the communication interface 108 is a

25   serial communication port, but could also alternatively be any of a number of

well known communication standards and protocols, e.g., Universal Serial Bus (USB), Ethernet, FireWire (IEEE 1394), parallel, small computer system interface (SCSI), infrared (IR) communication, Bluetooth wireless communication, etc.

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Optionally, computer system 100 can include a display device 112 which is coupled to bus 110 for displaying graphics and/or video. It should be appreciated that optional display device 112 may be a cathode ray tube (CRT), flat panel liquid crystal display (LCD), field emission display (FED), or any other

10 display device suitable for displaying video and/or graphic images and alphanumeric characters recognizable to a user. Furthermore, system 100 can include an optional alphanumeric input device 114 including alphanumeric and function keys coupled to the bus 110 for communicating information and command selections to the central processor(s) 102.

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Additionally, the computing device 100 of Figure 1 can include an optional cursor control or cursor directing device 116 coupled to the bus 110 for communicating user input information and command selections to the central processor(s) 102. The cursor directing device 116 can be implemented using a

20 number of well known devices such as a mouse, a track-ball, a track pad, an optical tracking device, a touch screen, etc. Alternatively, it is appreciated that a cursor can be directed and/or activated via input from alphanumeric input device 114 using special keys and key sequence commands. The present invention is also well suited to directing a cursor by other means such as, for

25 example, voice commands. In addition, the cursor directing device 116 can

HP-10011098

also be a remote control device (e.g., a universal remote control device having

a number of buttons, dials, etc.) with an infra-red signal communication

capability. System 100 can also include a computer usable mass data storage

device 118 such as a magnetic or optical disk and disk drive coupled with bus

5 110 for storing information and instructions.

METHOD FOR AUTOMATED DIGITAL IMAGE ENHANCEMENT

10 Figures 2-3 show methods 200 and 300 that illustrate steps performed in

accordance with embodiments of the present invention for automated digital

image enhancement. Methods 200 and 300 include processes of the present

invention which, in one embodiment, are carried out by processors and

electrical components under the control of computer readable and computer

15 executable instructions. The computer readable and computer executable

instructions reside, for example, in data storage features such as computer

usable volatile memory 104 and/or computer usable non-volatile memory 106

of Figure 1. However, the computer readable and computer executable

instructions may reside in any type of computer-readable medium. In one

20 embodiment of the present invention a computer readable medium is used to

store instructions for performing the method of the present invention. In this

embodiment the computer-readable medium is a magnetic or optical storage

device such as a disk drive, magnetic tape, Compact Disk(CD), DVD (digital

versatile disk or digital video disk). In yet another embodiment, the method of

25 the present invention is performed using computer instruction signals embodied

in a transmission medium (with or without a carrier wave upon which the

HP-10011098

signals are modulated). For example, the transmission medium may include a communications network such as the Internet.

Although specific steps are disclosed in methods 200 and 300 of Figures

5   2-3, such steps are exemplary. That is, the present invention is well suited to performing various other steps or variations of the steps recited in Figures 2-3. Within the present embodiment, it should be appreciated that the steps of methods 200 and 300 may be performed by software or hardware or any combination of software and hardware.

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As shown by step 201 of Figures 2-3, human faces are located within the digital image. In the present embodiment, a face detection algorithm is applied to the digital image for locating faces within the digital image. In one embodiment, a neural network based algorithm is applied to the digital image to

15   identify any faces within the digital image.

In the embodiment shown in Figure 2, the digital image can be manipulated using the format in which it is received or using any of a number of different common formats for analysis and manipulation of the digital image.

20

In the embodiment shown in Figure 3, each digital image is converted from its original format into L *a*b* color space as shown by step 310. For convenience, the present invention is described with reference to L*a*b* color space in the remainder of the detailed description. However, it is appreciated

25   that other formats and corresponding tone mapping values could also be used.

HP-10011098

As shown by step 202, the digital image is analyzed. In the present embodiment, the analysis includes analysis of the faces located in step 201 and the analysis of the digital image as a whole.

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Continuing with step 202, in the present embodiment, the regions of the image that were identified to be human faces are analyzed to determine average face region lightness (L_f). Average face region lightness can be determined by calculating the mean of the L* level of the human faces detected

10   in the digital image. In the present embodiment, the human faces are also analyzed to determine face region contrast.

In the present embodiment, the entire picture is analyzed to determine average picture lightness (L_p). The average picture lightness can be

15   determined by calculating the mean of the L* level of the whole picture. The entire picture is also analyzed for determining digital resolution and histogram uniformity.

A tone mapping function is then determined as shown by step 203 for

20   enhancing the image quality of the digital image. In the present embodiment, the tone mapping function is a one-dimensional global function that maps one input value to only one output value. In one embodiment, the tone mapping function is based on the statistical measurement of the whole image as well as the measurement of face regions contained in the digital image. In the present

25   embodiment, the face region(s) are treated as a region of interest and are

HP-10011098

treated independently in the determination of the tone mapping function as compared to the image as a whole.

In the present embodiment, the psychological factors of face region lightness and average picture lightness are used in addition to signal factors(digital resolution, face region contrast, histogram uniformity and noise issue) in determining the tone mapping function.

The tone mapping function can be represented in graphical form by a tone mapping curve. In the present embodiment, the tone mapping curve is an integer-to-integer mapping curve in which both x and y integers are in the range of from 0 to 255. This conforms to the range of lightness (L) within a conventional L*a*b* format. However, other ranges can be used to accommodate different formats.

In the embodiment shown in Figure 3, the tone mapping function is determined (step 203) by first designing the tone mapping curve as shown by step 311 and using the tone mapping curve to generate a look-up table as shown by step 312.

As shown by step 204, the tone mapping function determined in step 203 is applied to the digital image so as to produce an enhanced digital image. In the embodiment shown in Figure 3, the tone mapping function is applied to the digital image by mapping the L* values using the look-up table. More particularly , in the present embodiment, each L* value within the digital image

HP-10011098

is replaced with a corresponding L* value from the lookup table. Thereby, the tone values of the original digital image are altered, producing an enhanced digital image.

5   In the embodiment shown in Figure 3, the digital image is converted back into its original format. More particularly, the image is changed from the L*a*b* format back into the original format or "color space".

In the present embodiment, steps 201 through 204 of Figures 2-3 and

10   steps 310-314 of Figure 3 are performed automatically and without any user input. In one embodiment, the steps of methods 200 and 300 are performed by a computer program upon initiation of the computer program to perform the method of the present invention. The computer program then performs steps of methods 200 and 300 automatically, resulting in the creation of an enhanced

15   digital image. In the present embodiment, the program does not require the user to provide any input or make any choices between different options to obtain the resulting output of an enhanced digital image.

The tone mapping process of the present invention only alters the L*

20   value, leaving the a* and b* components unchanged. This approach improves the lightness distribution of the digital image while maintaining the original chromatic information.

HP-10011098

TONE MAPPING FUNCTION

a. Psychological Factors

Because human eyes adapt rapidly to the level of a relatively small angle in the visual field around the current fixation point, human eyes are only

5   sensitive to relative luminance difference rather than absolute luminance difference. Accordingly, the psychological factors in the tone mapping function of the present are designed from two aspects, average face region lightness (L_f) and average picture lightness (L_p).

10   It has been found that human observers prefer to have both human face lightness L_f and picture lightness L_p to be mapped to specific optimal values optimal human face lightness (L^o_f) and optimal picture lightness (L^o_p). Human face lightness L_f and picture lightness L_p are coupled in influencing the subjective quality evaluation of an image. However, the two optimal values of

15   optimal human face lightness L^o_f and optimal picture lightness L^o_p. can not always be obtained for a particular digital image. For example, one bright face may be captured with a dark background.

It has been found that human evaluation of picture quality is pretty

20   gradual with respect to the values of human face lightness L_f and picture lightness L_p. Therefore, some pictures still get good quality evaluation with their human face lightness L_f and picture lightness L_p close to the optimal values. The tone mapping function of the present invention takes advantage of this by using optimal ranges instead of optimal values.

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HP-10011098

Figure 4 shows an example of an embodiment of the present invention in which optimal ranges are used for human face lightness L_f and picture lightness L_p. Along the axes of L_f and picture lightness L_p, their optimal region is defined as (L_f^{low}, L_f^{high}) and (L_p^{low}, L_p^{high}) respectively. With optimal range definitions for

5   human face lightness L_f and picture lightness L_p, pictures are classified into three categories: Dark, Normal and Bright along the two axes of human face lightness L_f and picture lightness L_p. When coupling these two parameters, pictures can be classified into nine categories in a two dimensional space. In the present embodiment, given a picture with parameters (L_f, L_p), psychological

10   based quality evaluation is represented as an energy term $E_{ps}(L_f, L_p)$. This gives a quality improvement problem that is formulated as an energy minimization (or maximization) problem in a two dimensional space as indicated by the following equation:

$$\min_{L_f, L_p} E_{ps}\left(L_f, L_p\right) \qquad (1)$$

15   To represent the coupled relationship between L_f and picture lightness L_p in determining the visual quality of the picture, the energy function E_{ps} is defined as a two dimensional function of human face lightness L_f and picture lightness L_p individually over the nine sub-regions that correspond to the nine image categories of Figure 4. In the present embodiment, the energy function E_{ps} is

20   defined as follows:

$$E_{ps}\left(L_f, L_p\right) = W_f^{(i)} \cdot \left(L_f - L_f^{o(i)}\right)^2 + W_p^{(i)} \cdot \left(L_p - L_p^{o(i)}\right)^2, \qquad (2)$$

where $L_f^{o(i)}$ and $L_p^{o(i)}$ represent the optimal mean L* value for the face and picture regions if the input image has the (L_f, L_p) pair located within the i-th region of Figure 4. A human face lightness weighting factor ($W_f^{(i)}$) and a picture lightness

25   weighting factor ($W_p^{(i)}$) are also used. Two different sets of optimal values (L_f^o,

$L_p^°$) are defined for human face lightness L_f and picture lightness L_p over the nine image categories/regions. For input images located within regions 1 to 8, both optimal human face lightness $L_f^°$, and optimal picture lightness $L_p^°$ are set to 120 (out of an 8-bit dynamic scale that runs from 0 to 255). However, images

5   that fall within region 9, will have an optimal human face lightness $L_f^°$, and optimal picture lightness $L_p^°$ that are both set to 141. In addition, the optimal region of both human face lightness L_f and picture lightness L_p are set as (100, 140).

10   Figure 5 illustrates an enhancement pattern produced by the present definition of quality evaluation when only psychological evaluation is considered. It can be seen that input pictures are divided into nine categories based on their picture level and ROI (face regions) statistics. With each category being represented as a state, the tone mapping function can be

15   modeled as a state machine in that it tries to push the input picture from one state into another new state by mapping the lightness of the pixels. The introducing of a separate set of optimal parameters for pictures in region 9 will ultimately lead to two absorbing states: state 5 and state 9 for this state machine. These two absorbing states represent the convergence output of the

20   present tone mapping algorithm if it is applied to an input image repeatedly. In practice, we find that this design helps better address human eye's sensitivity to the relative lightness and produces better visual results on these pictures with bright backgrounds.

25   b. Signal Factors

HP-10011098

Though psychological factors suggest that picture statistics human face lightness L_f and picture lightness L_p should be always mapped to their optimal values optimal human face lightness L_f^o, and optimal picture lightness L_p^o, in a global mapping scenario, Equation (2) can not be easily minimized because

5 human face lightness L_f and picture lightness L_p are not independent. They are each based on picture signals and constrained by certain signal features. Therefore in the present embodiment, a number of signal factors are also included into consideration for tone mapping design.

10 Digital resolution is a signal factor that is included in the present tone mapping function. For a 8-bit picture, it is desirable to make good use of 8-bit resolution. That is, the grayscale histogram of the picture should be distributed over the full range of values (in the present embodiment from 0 to 255). In the present embodiment, the concept of shadow L_s and highlight L_h are used to

15 compensate for digital resolution. Shadow L_s and highlight L_h both represent the grayscale boundary that clips the darkest (or brightest) 0.5 percent of the picture pixels. If shadow L_s is greater than zero or highlight L_h is less than 255, a linear stretch is applied to map shadow and highlight to the scale of from 0 to 255 to get full digital resolution of the picture.

20

Face region contrast, represented by the greyscale standard deviation of the face regions (δ), is a signal factor that is included in the present tone mapping function. Since human faces are considered as a region of interest, it is also desirable to use more digital grayscale resolution for face regions.

HP-10011098

Therefore, in the present embodiment, face region contrast δ is always increased when possible.

Histogram uniformity is a signal factor that is also included in the present tone mapping function. Though extreme uniformity of histogram (i.e., histogram equalization) is not desirable for consumer photos, uniformity of the histogram distribution is still an important factor from signal presentation point of view. Therefore, it is considered as a signal constraint.

Noise issue is another signal factor that is included in the present tone mapping function. The tone mapping function is an integer to integer mapping function that can be represented by a mapping curve. A large slope of the mapping curve tends to magnify small image noise, and is therefore a negative factor that is included in the present tone mapping function.

c. Tone Mapping Curve Design

The tone mapping function of the present invention is designed to cover both psychological and signal factors. Because psychological factors and signal factors are different semantics, in the present embodiment, their independent influences are combined with a system energy formulation. That is, the desirable tendency of the psychological and signal constraints are each formulated as their respective energy terms, psychological energy (E_{ps}) and signal factor energy (E_{signal}). The overall optimization of the tone curve design is then expressed as an energy minimization problem of the system energy term

Min(E) = min(E$_{ps}$ + E$_{signal}$). Here the minimization of the system energy is actually to find appropriate trade-offs between multiple constraints that contribute from different aspects to the same problem.

5   d. Parametric Curve Representation

The tone mapping function T: x ➔ y is an integer-to-integer mapping curve with both its input and output defined in the range of 0 to 255. To accommodate the mapping control of human face regions, the mapping function is designed as a two-segment gamma curve, an example of which is depicted in

10   Fig 6. In Fig 6, axis x represents the input and axis y represents the output grayscale respectively. L$_s$ and L$_h$ are the shadow and the highlight of the input image histogram and L$_{af}$ and L$_{mf}$ are the actual mean L* and the mapped mean L* of the face region. For simplicity of discussion, the control pair (L$_{af}$ and L$_{mf}$) is denoted as a control point (x$_o$, y$_o$) (i.e., L$_{af}$ = x$_o$ and L$_{mf}$ = y$_o$). The parametric

15   curve of the present invention then becomes:

$$\frac{y}{y_0} = \left(\frac{x - L_s}{x_0 - L_s}\right)^{a_1}, x \in [L_s, L_{af}] \tag{3}$$

$$\frac{1-y}{1-y_0} = \left(\frac{L_h - x}{L_h - x_0}\right)^{a_2}, x \in [L_{af}, L_h] \tag{4}$$

20

To decide the two gamma values a$_1$ and a$_2$, we require that the two segments be first order smooth at the control point (x$_o$, y$_o$). That is, their first

HP-1001 1098

order derivatives at this point are equal. If we denote this derivative as y', then we have the equations:

$$a_1 = \frac{x_0 - L_s}{y_0} \cdot y' \qquad (5)$$

$$a_2 = \frac{L_h - x_0}{1 - y_0} \cdot y' \qquad (6)$$

5   Therefore, the tone mapping curve as defined in Equations. (3)-(6) is fully decided by three parameters (x_0, y_0, y'). The design work is then to decide these three parameters based on the psychological and signal factors.

e. Determination of y'

10   In the present embodiment, y' is the slope of the curve at (x_0, y_0). It therefore controls the grayscale contrast of the mapped face region. If we denote the standard deviation of the L* signal of the face region before the tone mapping as δ_{af} and denote the standard deviation of the L* signal of the face region after the tone mapping as δ_{mf}, then the slope is $y' = \frac{\delta_{mf}}{\delta_{af}}$.

15

As detected face regions are considered as the region of interest, it is always desirable to increase the mapped deviation of the face regions δ_{mf} as long as it does not interfere with the grayscale distribution balance of the mapped picture. Therefore, we require that the mapped deviation of the face

20   region be greater than the deviation of the face region of the original digital image ($\delta_{mf} \geq \delta_{af}$).

In the present embodiment, the mapped deviation of face region is determined as follows. First, the histogram density at the neighborhood of L_{af} is

HP-10011098

measured over the histogram of the original picture using the following equation:

$$Density_{af} = \frac{\sum_{i=(L_{af}-\delta_{af}/3)}^{(L_{af}+\delta_{af}/3)} hist(i)}{2/3 \cdot (\delta_{af})} \qquad (7)$$

5   A histogram density ratio is then obtained by comparing this histogram density with the average histogram density of the picture using to the following equation:

$$k = \frac{Density_{af}}{width \cdot height / 255} \qquad (8)$$

The mapped deviation of the face region is then decided based on histogram

10   density ratio and a constant magnifying factor of 1.2 according to the equation:

$$\delta_{mf} = 1.2 \cdot k \cdot \delta_{af} \qquad (9)$$

Accordingly, in the present embodiment, a balance between histogram uniformity and better face region contrast is obtained. Considering the

15   consistency in the basic features of face regions, to avoid overdoing the contrast enhancement, we also set up an upper bound of δ_{mf}. This is, if δ_{mf} produced from Equation (9) makes $\delta_{mf} \geq \Delta_{max}$, we set $\delta_{mf} = \Delta_{max}$. After δ_{mf} is determined, the slope y is simply set as $\quad y' = \dfrac{\delta_{mf}}{\delta_{af}} \quad$.

20   f. Determination of (x_o, y_o)

The control point (x_o, y_o) is represented by the control pair (L_{af}, L_{mf}). In the present embodiment, L_{af} is obtained directly from face detection. If more than one face is detected, L_{af} is set as the weighted mean of the means of all the faces (weighted by the area of the faces).

HP-10011098

In the present embodiment, the mapped mean L* of face regions L_{mf} is determined based on system energy minimization as:

$$L_{mf} = y_0 = \arg\min_y \left(E_{ps}(y) + E_{signal}(y) \right) \quad (10)$$

In the present embodiment, E_{ps} is defined using Equation (2). Referring now back to Equation (2), $L_f = y$ and L_p is a function of y, once the slope y' is determined. Therefore, E_{ps} is a function of y while E_{signal} in Equation (10) is further decomposed into the following energy terms:

$$E_{signal}(y) = E_{uniformity}(y) + E_{model}(y) \quad (11)$$

In Equation (11), $E_{uniformity}$ represents the histogram uniformity of the mapped image:

$$E_{uniformity}(y) = \begin{cases} \dfrac{h_2(x_0)y}{h_1(x_0)(255-y)} - 1, & if \dfrac{h_2(x_0)y}{h_1(x_0)(255-y)} > 1 \\ \dfrac{h_1(x_0)(255-y)}{h_2(x_0)y} - 1, & otherwise \end{cases} \quad (12)$$

where $h_1(x_0) = \sum_{x=0}^{L_{af}} hist(x)$ and $h_2(x_0) = \sum_{x=L_{af}}^{255} hist(x)$ and where hist(x) is the histogram of the input picture before tone mapping.

In the present embodiment, the model energy term E_{model} in Equation (11) is defined as:

$$E_{model}(y) = D \cdot (y - x_0)^2 \quad (13)$$

where D is a weighting factor. This term is mainly intended to address the noise issue. That is, if the change in grayscale mapping is big, the slope will also be big and the noises on the original image tend to get magnified on the mapped

image. The weighting factor D compensates for magnificaton of the noises on the original image when the change in grayscale mapping is large.

The foregoing descriptions of specific embodiments of the present
5 invention have been presented for purposes of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise forms disclosed, and obviously many modifications and variations are possible in light of the above teaching. The embodiments were chosen and described in order to best explain the principles of the invention and its practical application,
10 to thereby enable others skilled in the art to best utilize the invention and various embodiments with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the Claims appended hereto and their equivalents.

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